MONOLITHIC INTEGRATION

OF

SEMICONDUCTOR AND SUPERCONDUCTOR COMPONENTS

DARPA/ONR Contract No. N00014-90-C-0226

Honeywell Sensor and System Development Center
10701 Lyndale Avenue South
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2.0 PROGRAM SUMMARY

The goal of the program is to develop transistor technology compatible with high transition temperature superconductor technology so that transistor pixel switches can be integrated with $YBa_2Cu_3O_7$ superconducting microbolometers in the same silicon substrate. A 4x4 matrix-addressable superconducting microbolometer array will be delivered at the completion of the program.

A technical breakthrough was accomplished in December, 1991, when a Honeywell-funded process run resulted in working single pixel and linear array superconducting microbolometers. Lessons learned from the first fabrication run (DARPA/ONR-funded) were incorporated in the Honeywell-funded run. A separate report will be issued on this breakthrough.

3.0 PROGRAM STATUS

Task 1.0: Vendor Selection

Mary Weybright, a graduate student in electrical engineering at Stanford University working under the direction of Prof. James D. Plummer, has been engaged as a consultant to model the performance of bipolar transistors at low temperature, in order to determine doping profiles needed for the transistor switches at each pixel.

Monolithic bipolar transistors from a potential vendor, ECI of Santa Clara, CA, have been tested after being subjected to 700° C for one hour. This heat treatment, which corresponds to that to be used in depositing YBaCuO on silicon substrates containing the transistors, did not change the device performance at room temperature.

The monolithic bipolar transistors will be fabricated by Honeywell's MICRO SWITCH Division of Richardson, Texas. Honeywell will pay for fabrication of these transistors. A request has been submitted to the Office of Naval Research to delete the transistor fabrication task from the contract, and for permission to allow Honeywell to donate the transistors to the contract. As of 31 December 1991, no response to this request has been received.

Task 2.0: First Fabrication Run (Completed)

Task 2.1: Film Development

Superconducting films of $YBa_2Cu_3O_7$ were grown in-situ on 3 - inch silicon wafers coated with amorphous silicon nitride and polycrystalline yttria stabilized zirconia. These films show onset of superconductivity at ~88 K and zero resistance at ~65 K. The temperature coefficient of resistance (TCR) is about 0.15 K^{-1} at the midpoint of the transition (~73 K). The substrates used are ideal for fabrication of microstructures by silicon micromachining techniques. These films were grown using a combination of pure ozone from Honeywell's ozone distillation system, and ordinary oxygen. The growth temperature for optimum superconducting properties was between 700° C and 735° C. These growth temperatures are believed to be low enough to allow survival of the transistors which will be embedded in the substrate.

Task 2.2: Mask Design

The first fabrication run used existing masks from DARPA/ONR Contract #N00014-88-C-0394.

Task 2.3: Vendor Electronics

For the first fabrication run, transistors were not embedded in the substrate.

Task 2.4: Integrated Device

No working bolometers were produced in the first fabrication run. The $YBa_2Cu_3O_7$ film on the bolometer structures was inadvertently removed by the KOH solution that was used to etch the silicon to thermally isolate the bolometers. In addition, the electrical contact pads did not adhere to the substrate. These problems were solved in a subsequent processing run funded by Honeywell which was completed in December, 1991.

Task 2.5: Device Evaluation

Room temperature resistance measurements were performed on the first two wafers of the first fabrication run.

Task 3.0: Second Fabrication Run

Task 3.1: Film Development

Superconducting films of $YBa_2Cu_3O_7$ have been grown in-situ on 3 - inch silicon wafers coated with amorphous silicon nitride and polycrystalline yttria stabilized zirconia. These films show onset of superconductivity at ~88 K and zero resistance at ~72 K. The temperature coefficient of resistance (TCR) is about 0.30 K^{-1} at the midpoint of the transition (~79 K). Thus, these films are superior to those used in the first fabrication run. A film with this TCR on a thermally isolated microstructure could provide a bolometer with a sensitivity which is high enough for high performance imaging applications using a staring array. The substrates used are ideal for fabrication of microstructures by silicon micromachining techniques. These films were grown using a combination of pure ozone from Honeywell's ozone distillation system, and ordinary oxygen. The growth temperature for optimum superconducting properties was between 700° C and 735° C. These growth temperatures are believed to be low enough to allow survival of the transistors which will be embedded in the substrate.

Noise measurements are being performed at the University of Minnesota, our subcontractor, on $DyBa_2Cu_3O_7$ films grown at the University of Minnesota on $SrTiO_3$ and $LaAlO_3$ single crystal substrates, and on $YBa_2Cu_3O_7$ films grown at Honeywell on silicon substrates with Si_3N_4/YSZ buffer layers. The emphasis in the $DyBa_2Cu_3O_7$ film measurements is on understanding the peak in the excess noise spectral density at the foot of the resistive transition. The emphasis in the $YBa_2Cu_3O_7$ film measurements is on understanding the noise near the midpoint of the resistive transiton, where a bolometer would be operated.

Task 3.2: Mask Design

The mask design for the transistor fabrication is complete, and these masks are being ordered from the mask vendor. The masks for the microbolometer fabrication are being designed. It is anticipated that these masks will be delivered before transistor fabrication is completed. The distance from the center of one pixel to the center of a neighboring pixel in the 4 x 4 array is 125 μm.

Task 3.3: Vendor Electronics

Mary Weybright, our consultant at Stanford University, has determined appropriate modifications to Honeywell MICRO SWITCH's bipolar transistor fabrication process which are designed to improve the performance of the transistors at low temperature. Data provided by Honeywell's MICRO SWITCH Division on their transistors at 298 K and 77 K have been used to determine the process modifications and predict the low temperature performance.

Task 3.4: Integrated Device

Work on this task has not begun.

Task 3.5: Device Evaluation

Preparations have been made for device evaluation, including writing computer software and setting up instrumentation. Devices fabricated in the recent processing run funded by Honeywell will be evaluated with this instrumentation.

Task 4.0: Third Fabrication Run

Work on this task has not begun.

4.0 ACCOMPLISHMENTS (for 1 October 1991 to 31 December 1991)

Task 1.0: Vendor Selection

The monolithic bipolar transistors will be fabricated by Honeywell's MICRO SWITCH Division in Richardson, Texas. Honeywell will pay for fabrication of these transistors. A request has been submitted to the Office of Naval Research to delete the transistor fabrication task from the contract, and for permission to allow Honeywell to donate the transistors to the contract. As of 31 December 1991, no response to this request has been received.

Task 2.0: First Fabrication Run (Completed)

Task 2.1: Film Development

No work was performed on this task during this period.

Task 2.2: Mask Design

The first fabrication run used existing masks from DARPA/ONR Contract #N00014-88-C-0394.

Task 2.3: Vendor Electronics

For the first fabrication run, transistors were not embedded in the substrate.

Task 2.4: Integrated Device

A design review meeting was held to determine the cause of failure to fabricate working bolometers in the first fabrication run. The results of this meeting were applied to successfully fabricate working bolometers in a process run funded by Honeywell.

Task 2.5: Device Evaluation

No work was performed on this task during this period.

Task 3.0: Second Fabrication Run

Task 3.1: Film Development

The $YBa_2Cu_3O_7$ film quality was improved by slightly increasing the barium content and increasing the amount of ozone present during film growth. Films grown in-situ on 3 - inch silicon wafers coated with amorphous silicon nitride and polycrystalline yttria stabilized zirconia have now shown an onset of superconductivity at ~88 K and zero resistance at ~72 K. The temperature coefficient of resistance (TCR) is about 0.30 K^{-1} at the midpoint of the transition (~79 K). A film with this TCR on a thermally isolated microstructure could provide a bolometer with a sensitivity which is high enough for high performance imaging applications using a staring array. The substrates used are ideal for fabrication of microstructures by silicon micromachining techniques. These films were grown using a combination of pure ozone from Honeywell's ozone distillation system, and ordinary oxygen. The growth temperature for optimum superconducting properties was between 700° C and 735° C. These growth temperatures are believed to be low enough to allow survival of the transistors which will be embedded in the substrate.

Noise measurements were performed at the University of Minnesota on $YBa_2Cu_3O_7$ films grown at Honeywell on silicon substrates with Si_3N_4/YSZ buffer layers. The excess noise in the superconducting transition region shows a 1/f frequency dependence from 2 Hz to 1000 Hz, with the noise power spectral density, $S_V(f)$, proportional to the square of the dc bias voltage. The value of Sv(f) increases as the temperature is decreased below the superconducting onset temperature. This indicates that to maximize signal to noise, it may be desirable to operate a bolometer at a temperature somewhat above the temperature where the infrared signal is maximized.

Task 3.2: Mask Design

The mask design for the transistor fabrication was completed. The distance from the center of one pixel to the center of a neighboring pixel in the 4 x 4 array is 125 μm. Transistors will be fabricated at Honeywell's MICRO SWITCH Division.

Task 3.3: Vendor Electronics

No work was performed on this task during this period.

Task 3.4: Integrated Device

Work on this task has not begun.

Task 3.5: Device Evaluation

Preparations were made for device evaluation, including writing computer software and setting up instrumentation. Devices fabricated in the recent processing run funded by Honeywell will be evaluated with this instrumentation.

Task 4.0: Third Fabrication Run

Work on this task has not begun.

5.0 PROBLEM AREAS/ISSUES

- Performance of transistors at low temperature must be adequate for good switching performance.
- Transistors must survive the high growth temperature of the $YBa_2Cu_3O_7$ films.
- The 1/f noise voltage in the $YBa_2Cu_3O_7$ films must be reduced. It is believed that the $YBa_2Cu_3O_7$ film growth temperature is sufficiently low to allow survival of the transistors. The resistive transitions presently being achieved are adequate for high performance staring array applications, and the films are smooth enough for bolometer

fabrication. The sharpness of the resistive transition has been shown to survive the processing steps required to fabricate bolometers.

- The electrical resistance of the gold contacts to the $YBa_2Cu_3O_7$ films must be low enough that small area (~10 μm x 10 μm) contacts have a resistance low compared to the bolometer resistance. Small area contacts are necessary for high fill-factor in the microbolometer pixels.

6.0 CORRECTIVE ACTION

- Utilize calculations of transistor performance to optimize low temperature performance.
- Use PtSi ohmic contacts to the transistors.
- Adjust $YBa_2Cu_3O_7$ film and substrate buffer layer growth parameters to optimize $YBa_2Cu_3O_7$ film properties, with emphasis on minimizing the noise.
- Reduce electrical contact resistance by depositing gold in-situ by ion beam sputtering immediately after deposition of the $YBa_2Cu_3O_7$ film. The gold film will then be photolithographically patterned into the desired contact geometry.

7.0 GOALS FOR THE NEXT PERIOD (1 January 1992 to 31 March 1992).

- Test the process for making small area electrical contacts to the $YBa_2Cu_3O_7$ films by depositing gold films in-situ by ion beam sputtering.
- Complete the characterization of bolometers fabricated in the recent fabrication run funded by Honeywell. Characterization of these devices will be funded under this contract.
- Complete the microbolometer mask design for the second fabrication run and obtain the completed masks.
- Complete fabrication of the silicon substrates with embedded transistors for the second fabrication run (transistor fabrication funded by Honeywell).

8.0 PUBLICATIONS

8.1 Papers Published in Refereed Journals

None

8.2 Papers Published in Conference Proceedings

None

8.3 Presentations

a. Invited

B.R. Johnson, "Superconducting Microbolometer Infrared Detector Arrays on Silicon Microstructures," presented at the International Superconductor Applications Convention, San Diego, CA, January 14-16, 1991.

b. Contributed

B.R. Johnson, P.W. Kruse, and S.B. Dunham, "$YBa_2Cu_3O_7$ Films For Infrared Bolometers on Silicon Microstructures," presented at the Materials Research Society Fall Meeting, December 2-6, 1991, Boston, MA.

E. Nowak, N. Israeloff, T. Wang, A.M. Goldman, "Voltage Noise Probe of Vortex Dynamics in High - T_c $DyBa_2Cu_3O_7$ Thin Films", presented at the Materials Research Society Fall Meeting, December 2-6, 1991, Boston, MA.

The following paper was presented at the DARPA Second Annual High Temperature Superconductors Workshop, Sheraton Tara Hotel and Resort, Danvers, MA, October 3-5, 1990.

B.R. Johnson, C-J Han, T. Ohnstein, B.E. Cole and P.W. Kruse, "Monolithic Integration of Semiconductor and Superconductor Components."

The following paper was presented at the DARPA Third Annual High Temperature Superconductors Workshop, Hyatt Bellevue Hotel, Bellevue, Washington, September 30 - October 2, 1991.

B.R. Johnson, T. Ohnstein, P.W. Kruse and S. B. Dunham, "$YBa_2Cu_3O_7$ Films for Infrared Bolometers on Silicon Microstructures."

9.0 FINANCIAL

A.	Funding Authorized	\$300,000
B.	Funds Expended or Committed (Week ending)	\$395,094
C.	Additional Funds Required to Complete Contract (t y 30 June 1992)	\$351,293

Program Schedule